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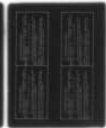   RESIN SYSTEMS AND GLASS REINFORCEMENTS TO IMPROVE DRY-FORMED HA--ETC(U)
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RESIN SYSTEMS AND GLASS REINFORCEMENTS TO IMPROVE DRY-FORMED HARDBOARDS

10 R. E. Steinmetz

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Abstract

Various resin systems and quantities of resin and a glass yarn scrim were investigated to determine whether they improved stiffness and linear stability of dry-formed, medium- and high-density hardboards. The following resins were used : A low-viscosity (penetrating) and a medium-viscosity (typical bonding type) phenolic, separately, in combination, or viscosity-modified; a two-part epoxy resin; and a powdered thermoplastic resin either separately or in combination with the low-viscosity phenolic. Increasing the quantity of phenolic resin improved both wet-formed and dry-formed board properties but at a diminishing rate with the increase. The low-viscosity phenolic or a combination of the low- and the medium-viscosity phenolic resulted in the best boards.

The powdered thermoplastic resin in combination with the low-viscosity phenolic resin provided boards with good wet and dry properties. If analyzed on a total cost basis, this combination of resins has potential as a substitute for phenolic resin. The epoxy system was difficult to handle because of its high viscosity and the tackiness of the fiber after resin was applied. Board strengths were low. The glass yarn scrim pretreated with phenolic resin and bonded to each side of the hardboard mat was highly effective, especially in reducing board linear movement with changes in moisture.

Acknowledgment

RESIN SYSTEMS AND GLASS REINFORCEMENTS TO IMPROVE DRY-FORMED HARDBOARDS

By

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Introduction

As availability of high-quality timber and related wood products decreases, the need for quality substitutes that are economically competitive is obvious.

Characteristics of wood fiber base hardboards make them desirable for specific uses. However, their expansion into new product areas has been restricted due to insufficient stiffness and dimensional stability.

Improved stiffness in high-density and medium-density hardboards will enable the boards to be used to a greater extent as structural components. This is desirable because hardboards inherently use wood fiber efficiently -- whether from logs or from forest or urban residues. Prior work at the Forest Products Laboratory indicated that improved boards could be made by combining different types of phenolic resin to take advantage of the best characteristics of each type.

Glass fibers or yarns are characterized by their high strength and stiffness. Because of these properties they have been used as reinforcements in plastic laminates that have resulted in exceptionally strong and stiff composites. It is generally known that linear stability can be improved if glass fibers are added to paper and hardboard furnishes. The inherent strength and the stiffness of these glass fibers, however, have not been realized because of inadequate bond between wood fibers and glass fibers.

This study was undertaken to determine how the following conditions affected board properties--particularly stiffness--of medium-density and high-density hardboards: Increasing quantity of phenolic resin; substituting other binders for the phenolic resin; adjusting viscosity of the phenolic resin; using a dual phenolic resin system; substituting a less expensive binder for varying portions of the phenoic resin; or adding glass yarn scrim to form hardboard sandwich combinations.

Experimental

Fiber

Aspen fiber commercially prepared and obtained without additives was used for all boards except boards with ponderosa pine fiber that were combined with glass yarn scrim. The fibers of both wood species were obtained after pressurized disk refining and drying to 25 percent moisture content.

Resins

Two water-soluble board-type phenolic resins, a low-viscosity resin and a medium-viscosity resin, were used. They were diluted to 24 percent solids for spraying onto the fiber. The low-viscosity resin was a low-molecular weight, penetrating type with an "as shipped" solids content of 77 percent, and when diluted had a viscosity of 11 centipoises. The other resin was a commonly used medium-viscosity with an "as shipped" solids content of 48 percent, and when diluted had a viscosity of 28 centipoises.

A two-part epoxy resin system was used; both parts were at 100 percent solids blended in a 1:1 volume ratio. The combined viscosity was 576 centipoises with a curing time of 5 to 7 minutes at 350° F.

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A thermoplastic resin, a dimethyl therylate derivative, was obtained in dry pulverized form. The resin was mixed with water to a 24-percent solids content for applying to the fiber; its viscosity in the water suspension was 30 centipoises.

Glass Yarn Scrim

The glass yarn scrim used in most of the boards weighed 2.3 ounces per square yard. Fifty-four yarns per foot were in the principal direction; 8 yarns per foot in the cross direction. Heavier and lighter yarns with different weaves were tried in preliminary board trials, but their cost-performance relationship was not as favorable as the yarn used. Preliminary board experiments also showed that the resin on the wood fiber even at the high levels was insufficient to give a satisfactory bond between the glass yarn and the wood fiber.

In preliminary trials with different types and amounts of pretreatment resin for the glass scrim it was established that about 16 percent of an alcohol-soluble phenolic resin based on the treated weight of the glass was required to give optimum bond. With less resin or other types of resin, the board failure in bending was a result of shear between the glass and the wood fiber network.

Application of Resin

The resins were applied to the fiber in a rotating drum by a sprayer with a fan-shaped nozzle; the pattern of spray was directed at the falling fiber brought past midpoint by internal baffles. Two batches of fiber were treated and mixed together or four batches when the high-density and the medium-density furnish had the same resin content for each resin or resin combination. When the penetrating-type phenolic resin was used in combination with another resin, it was sprayed first, except in one series in which the two phenolics were mixed together, and sprayed in a single step.

The quantity of resin added was based on the dry weight of chemical and expressed as a percentage of the weight of dry fiber.

The treated fiber was dried to a moisture content of about 10 percent in a circulating air atmosphere at about 90° F. The fiber was stored overnight in a plastic bag in a controlled environment of 70° F and 50 percent relative humidity (RH).

Boardmaking

Three mats, 14 by 14 inches, were formed representing each board type using a "banjo" type former. The forming box has monofilament strings at 1/4-inch intervals in both directions. The treated fiber was placed on this mesh network. The strings were then alternately displaced in the horizontal plane allowing the fiber bundles to be separated and fall through to a metal caul below. To densify, the mats were cold pressed, then hot pressed for 6 minutes at 385° F to thickness. They were given no further heat treatment.

The treated glass scrim was applied to each surface of the preformed wood fiber mats prior to prepressing. Two layers of yarn were applied to some mats. Preliminary mats were formed by placing the glass scrim at various locations throughout the mat as it was being formed, but the most efficient use of the glass was noted if it was applied to the surface.

Board Evaluation

All of the boards were conditioned for 30 days at 50 percent RH and 72° F before testing. Dry-board flexural strength, tension parallel to surface, and internal bond were determined according to ASTM methods.[2] Wet-board strengths were determined after 8-day immersion in water. Stiffness properties were calculated from data for bending and tension.

Length and thickness changes were determined on nine specimens (6 inches by 1/2 inch) from each set of boards representing all resin systems, combinations, and modifications and on six specimens (6 inches by 1/2 inch) representing the different glass-containing boards.

After initial conditioning, at 50 percent RH and 72° F the following were exposed simultaneously for 30 days: One-third of the specimens of each type, at 80 percent RH and 80° F; one-third at 90 percent RH and 80° F; and one-third to immersion in water 1 inch deep to allow all samples to reach equilibrium conditions. Length and thickness were recorded before and after each of these exposures. Stainless steel balls, 1/8-inch diameter, were embedded with epoxy glue in the ends of each specimen to eliminate errors in measurement due to edge compression or crushing.

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[2]American Society for Testing and Materials. 1975. Standard methods of evaluating the properties of wood-base fiber and particle panel materials. ASTM D 1073. In ASTM standards. Pt. 16.

The tests on the boards with glass yarn scrim were conducted in the direction with the greater number of glass strands.

Results

Type of Resin

At a particular resin level, the phenolics resulted in the highest strength, the greatest stiffness, and in the most satisfactory performance of board dimensional properties. The low-viscosity phenolic generally performed more satisfactorily than did the medium viscosity. This probably resulted from sufficient resin being available for a portion to be absorbed into the fiber to stiffen it and keep moisture from being absorbed and for a portion to remain on the fiber surfaces to provide bonding between fibers. This response was also evident in the dimensional properties of the two phenolics (tables 1 and 2).

The epoxy resin did not provide effective strength and stiffness to the boards, although dimensional properties were similar to those of the boards with medium-viscosity phenolic resin. The ineffectiveness of the epoxy resin may be due in part to the high viscosity (576 centipoises) that made this resin difficult to distribute uniformly on the fiber -- at least with our spraying system. This resin was tacky, and it was difficult to form the mat without fiber clumps. To improve spraying consistency, epoxy resins with lower viscosity than used here should be considered in future work.

With equal resin content, the medium-density boards with powdered thermoplastic resin had dry stiffness properties equivalent to the low-viscosity phenolic resin boards.

In the high-density boards, bending modulus was higher with the thermoplastic resin, whereas tensile modulus was higher with the phenolic. However, strength properties of both medium- and high-density boards were somewhat lower with the thermoplastic resin than with the phenolics; linear stability likewise was lower. The boards with thermoplastic resin retained 25 to 35 percent of their dry strength and stiffness after soaking in water compared to 50 percent or more for the boards with phenolic resin. The cost of the thermoplastic resin is one-fourth to one-third that of the phenolic resin. On an equal cost basis, that is 12 percent thermoplastic versus 4 percent phenolic resin, dry strength and stiffness, thickness, swell, and water absorption were improved with the thermoplastic resin.

The wet properties and the linear stability, however, were not as satisfactory with the thermoplastic resin.

Phenolic-Thermoplastic Combinations

Combinations of the low-viscosity phenolic and the thermoplastic resins were used successfully to provide boards either with dry-board strength and stiffness comparable to an all-phenolic resin board at a reduced binder cost or with improved overall properties at the same binder cost.

In the high-density boards with equal quantities of the phenolic and the thermoplastic resins, the dry bending strength and stiffness were comparable or greater than in the all-phenolic treated boards (figs. 1 and 2). This was achieved at a reduced total resin cost. However, the wet-board strength properties were somewhat lower. But when comparing on an equal resin/cost basis, for example, 4 percent phenolic versus 2 percent phenolic plus 6 percent thermoplastic resin, the boards with the resin combination were improved in all properties--even wet-board properties and dimensional stability. The range of improvement varied from a low of 7 percent for internal bond to a high of 60 percent for tensile modulus after water soaking (table 3).

Similar trends were noted in the medium-density boards in which powdered thermoplastic resin was substituted for the low-viscosity phenolic resin (table 4). Comparing boards with 4 percent phenolic plus 8 percent thermoplastic resin to boards with 8 percent phenolic resin, the wet-board and dry-board mechanical properties (figs. 3 and 4) and linear stability were comparable or improved over those of the all-phenolic-treated boards. Indications are that all properties would be improved if additional thermoplastic resin had been used to give a more equitable cost comparison.

Amount of Phenolic Resin

Board properties generally improved with increased phenolic resin, but not necessarily in direct proportion to the percent increase of resin. The improvements were greater for given resin increases when compared under wet conditions than under dry conditions. For example, comparing the high-density boards with 8 percent phenolic to those with 4 percent phenolic, the increase in dry-board bending modulus and in tensile modulus were 10 percent and 25 percent, respectively, whereas

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Table 1.--Physical[1]/ and dimensional[2]/ properties of 3/16-inch thick high-density dry-formed aspen hardboards

Resin			Board properties when tested:[3]/									Dimension change with moisture change from 50-90 pct RH[4]/	
			Dry					Wet (after 8-day immersion in water)[4]/					
			Static bending		Tension			Static bending		Tension			
Type	Amount	Viscosity	Modulus of rupture	Modulus of elasticity	Maximum stress	Modulus of elasticity	Internal bond	Modulus of rupture	Modulus of elasticity	Maximum stress	Modulus of elasticity	Length	Thickness
	Pct	CP	Lb/in.²	1,000 lb/in.²	Lb/in.²	1,000 lb/in.²	Lb/in.²	Lb/in.²	1,000 lb/in.²	Lb/in.²	1,000 lb/in.²	Pct	Pct
EFFECT OF RESIN TYPE													
Phenolic, low-viscosity	12	11	11,500 (6.5)	1,040 (8.0)	7,390 (5.4)	1,080 (5.5)	720 (15.6)	--	--	--	--	0.18 (9.6)	5.6 (9.7)
Phenolic, medium-viscosity	12	28	11,600 (11.6)	910 (12.2)	6,040 (24.7)	900 (22.6)	370 (34.2)	--	--	--	--	.26 (12.7)	6.5 (6.5)
Epoxy	12	576	4,520 (9.7)	540 (8.3)	2,890 (9.2)	550 (7.4)	230 (16.7)	2,020 (7.4)	210 (5.8)	1,020 (11.2)	120 (4.9)	.25 (4.0)	8.4 (1.1)
Phenolic, low-viscosity	8	11	7,240 (26.5)	720 (19.1)	5,770 (6.7)	1,000 (23.5)	370 (6.1)	5,130 (22.7)	500 (17.3)	3,650 (15.5)	470 (8.1)	.7 (3.5)	5.5 (2.4)
Thermoplastic	8	30	5,710 (18.1)	880 (13.5)	3,040 (5.5)	820 (1.0)	270 (12.9)	2,290 (13.4)	310 (7.7)	770 (11.8)	160 (11.2)	.22 (.0)	7.6 (6.3)
EFFECT OF PHENOLIC RESIN AMOUNT													
Phenolic, low-viscosity	2	11	5,040 (4.8)	710 (6.2)	3,930 (10.6)	790 (8.0)	240 (21.5)	2,620 (11.6)	310 (15.8)	1,480 (10.8)	260 (9.1)	.20 (3.0)	8.5 (8.6)
	4	`11	5,700 (5.5)	650 (4.0)	3,280 (21.7)	800 (25.1)	270 (7.0)	2,980 (10.7)	330 (8.2)	1,470 (14.7)	230 (8.3)	.20 (7.5)	8.0 (0.8)
	8	11	7,240 (26.5)	720 (19.1)	5,770 (6.7)	1,000 (23.5)	370 (6.1)	5,130 (22.7)	500 (17.3)	3,650 (15.5)	470 (8.1)	.17 (3.5)	5.5 (2.4)
	12	11	11,500 (6.5)	1,040 (8.0)	7,390 (5.4)	1,080 (5.5)	720 (15.6)	--	--	--	--	.18 (9.6)	5.6 (9.7)
EFFECT OF PHENOLIC VISCOSITY													
Phenolic, low-viscosity	12	11	11,500 (6.5)	1,040 (8.0)	7,390 (5.4)	1,080 (5.5)	720 (15.6)	--	--	--	--	.18 (9.6)	5.6 (9.7)
	12	5/30	11,390 (6.9)	1,070 (8.5)	6,720 (12.6)	960 (8.8)	700 (8.2)	--	--	--	--	.17 (.0)	5.1 (.0)
	12	5/90	9,540 (10.0)	930 (7.4)	6,540 (12.5)	1,000 (8.8)	540 (14.5)	--	--	--	--	.19 (.0)	5.8 (1.3)

1/ Tested according to ASTM D 1037 (see text, footnote 2); values adjusted to density of 60 pounds per cubic foot.

2/ Equilibrium conditioned at each relative humidity (RH) for 30 days.

3/ Values in parentheses are coefficients of variation calculated from individual data values.

4/ Based on dimension at 50 percent RH.

5/ Carboxymethylcellulose added to change viscosity.

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Table 2.--Physical[1] and dimensional[2] properties of 3/16-inch thick medium-density dry-formed aspen hardboards

Resin			Board properties when tested:[3]									Dimension change with moisture change from 50-90 pct RH[4]	
Type	Amount	Viscosity	Dry					Wet (after 3-day immersion in water)[4]					
			Static bending		Tension		Internal bond	Static bending		Tension		Length	Thickness
			Modulus of rupture	Modulus of elasticity	Maximum stress	Modulus of elasticity		Modulus of rupture	Modulus of elasticity	Maximum stress	Modulus of elasticity		
	Pct	Cp	Lb/in.²	1,000 lb/in.²	Lb/in.²	1,000 lb/in.²	Lb/in.²	Lb/in.²	1,000 lb/in.²	Lb/in.²	1,000 lb/in.²	Pct	Pct
			EFFECT OF RESIN TYPE[4]										
Phenolic, low-viscosity	12	11	5,450 (9.3)	570 (7.1)	3,330 (6.8)	550 (6.1)	190 (18.9)	--	--	--	--	0.14 (4.2)	5.5 (4.4)
Phenolic medium-viscosity	12	28	5,640 (21.0)	490 (16.2)	3,550 (9.6)	470 (6.2)	180 (8.3)	--	--	--	--	.23 (10.3)	6.7 (5.1)
Epoxy	12	576	1,630 (6.6)	260 (2.7)	1,120 (5.0)	300 (4.7)	70 (27.0)	650 (9.5)	90 (6.8)	340 (3.0)	70 (2.4)	.34 (4.7)	10.8 (5.5)
Thermoplastic	12	30	2,810 (10.5)	540 (7.8)	1,750 (6.9)	540 (3.8)	70 (21.4)	850 (4.6)	150 (1.9)	420 (13.5)	100 (22.2)	.22 (5.1)	7.4 (0.7)
			EFFECT OF PHENOLIC RESIN AMOUNT[4]										
Phenolic, low-viscosity	4	11	2,140 (17.8)	360 (10.0)	1,420 (24.4)	370 (16.6)	60 (7.1)	1,210 (16.2)	180 (8.6)	550 (23.6)	120 (21.9)	.21 (10.0)	9.8 (5.1)
	8	11	3,460 (12.5)	440 (10.0)	2,500 (20.3)	470 (12.7)	110 (26.1)	2,460 (11.3)	310 (12.2)	1,380 (13.6)	250 (7.9)	.15 (.0)	6.1 (8.5)
	12	11	5,450 (9.3)	570 (7.1)	3,320 (6.8)	550 (6.1)	190 (18.9)	--	--	--	--	.14 (4.2)	5.5 (4.4)
	16	11	4,850 (10.1)	510 (4.9)	2,750 (13.7)	480 (9.5)	230 (7.0)	3,760 (3.3)	400 (3.5)	1,820 (15.5)	340 (3.4)	.11 (18.4)	4.0 (9.3)
			EFFECT OF PHENOLIC VISCOSITY[4]										
Phenolic, low-viscosity	12	11	5,450 (9.3)	570 (7.1)	3,330 (6.8)	550 (6.1)	190 (18.9)	--	--	--	--	.14 (4.2)	5.5 (4.4)
	12	[5]30	5,360 (10.6)	570 (7.2)	3,030 (11.0)	520 (7.6)	190 (17.6)	--	--	--	--	.13 (8.1)	5.1 (5.1)
	12	[5]90	4,610 (8.5)	530 (5.5)	2,960 (10.3)	540 (6.6)	180 (8.2)	--	--	--	--	.15 (3.9)	5.6 (5.0)

1/ Values adjusted to density of 45 pounds per cubic feet and tested according to ASTM D 1037 (see text, footnote 2).
2/ Equilibrium conditioned at each relative humidity (RH) for 30 days.
3/ Values in parentheses are coefficients of variation calculated from five individual values
4/ Based on dimension at 50 percent RH.
5/ Carboxymethylcellulose added to change viscosity.

Figure 1. -- Relationship of modulus of elasticity (bending) of high-density hardboards to resin content (phenolic (P) resin, powdered thermoplastic (T) resin, and combinations of the two).

(M 144 688)

Figure 2. -- Relationship of modulus of rupture (MOR) and tensile strength (TS) of high-density hardboards to resin content (phenolic (P) resin, powdered thermoplastic (T) resin, and combinations of the two).
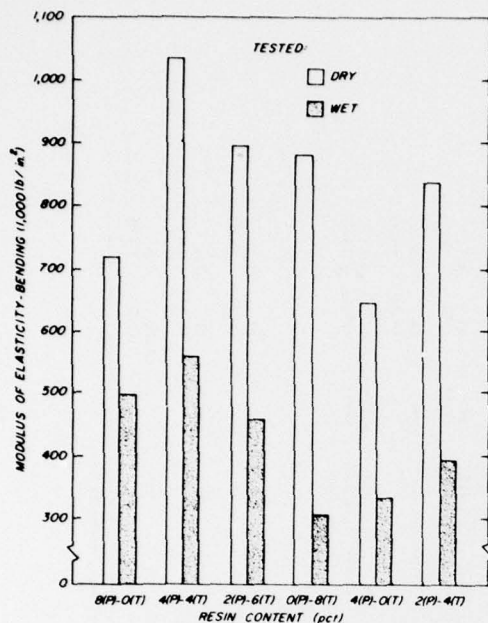
(M 144 689)

Figure 3. -- Relationship of modulus of elasticity (bending) of medium-density hardboards to resin content (phenolic (P) resin, powdered thermoplastic (T) resin, and combinations of the two).
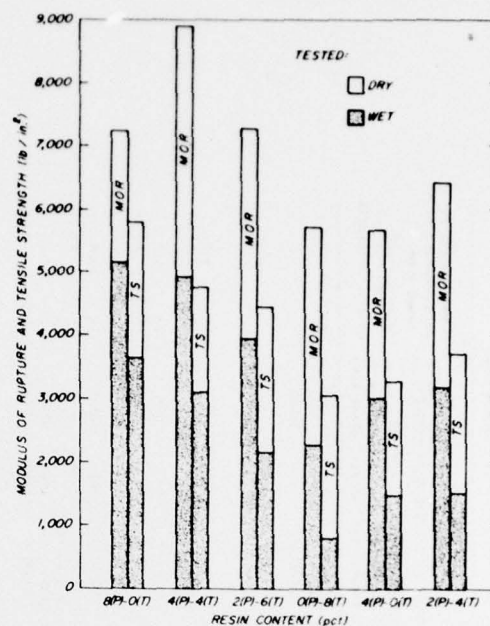
(M 144 685)

Figure 4. -- Relationship of modulus of rupture (MOR) and tensile strength (TS) of medium-density hardboards to resin content (phenolic (P) resin, powdered thermoplastic (T) resin, and combinations of the two).
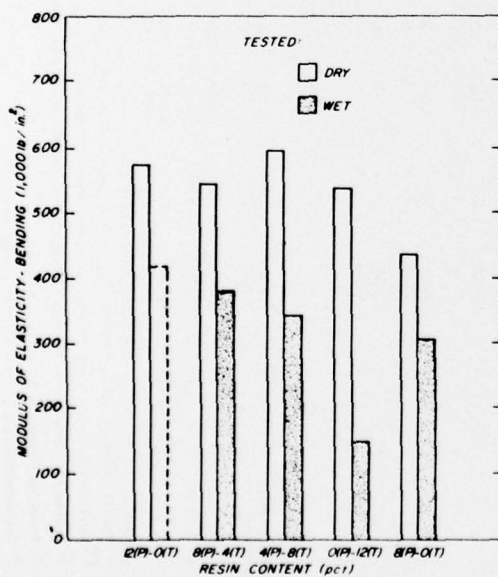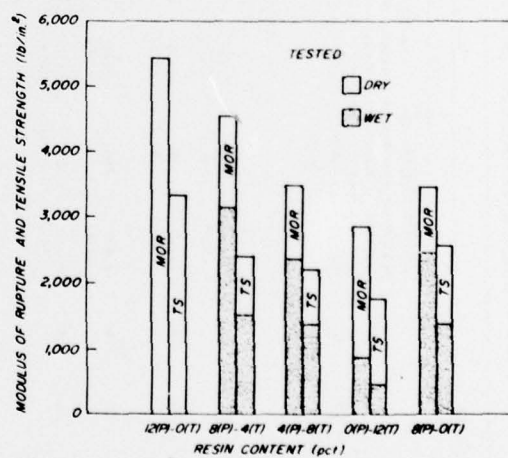
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Table 3.--Physical [1] and dimensional [2] properties of 3/16-inch thick high-density dry-formed aspen hardboards

Resin and amount		Board properties when tested: [3]										Dimension change [4] with moisture change from 50-90 pct RH	
Low-viscosity phenolic	Other [5]	Dry					Wet (after 8-day immersion in water) [4]						
		Static bending		Tension		Internal bond	Static bending		Tension			Length	Thickness
		Modulus of rupture	Modulus of elasticity	Maximum stress	Modulus of elasticity		Modulus of rupture	Modulus of elasticity	Maximum stress	Modulus of elasticity			
Pct	Pct	Lb/in.²	1,000 lb/in.²	Lb/in.²	1,000 lb/in.²	Lb/in.²	Lb/in.²	1,000 lb/in.²	Lb/in.²	1,000 lb/in.²		Pct	Pct
PHENOLIC-THERMOPLASTIC COMBINATIONS [5]													
8	0	7,240 (26.5)	720 (19.1)	5,770 (6.7)	1,000 (23.5)	370 (6.1)	5,130 (22.7)	500 (17.3)	3,650 (15.5)	470 (8.1)		0.17 (3.5)	5.5 (2.4)
4	4	8,970 (15.6)	1,030 (5.8)	4,750 (17.3)	830 (11.2)	260 (42.3)	4,940 (12.3)	560 (16.6)	3,070 (15.0)	380 (11.3)		.19 (2.8)	4.9 (5.6)
2	6	7,250 (12.5)	890 (8.4)	4,450 (5.7)	880 (4.7)	290 (19.1)	3,970 (9.5)	460 (6.6)	2,150 (6.9)	360 (9.2)		.19 (3.0)	6.2 (6.7)
0	8	5,710 (18.1)	880 (13.5)	3,040 (5.5)	820 (1.0)	270 (12.9)	2,290 (13.4)	310 (7.7)	770 (11.8)	160 (11.2)		.22 (.0)	7.6 (6.3)
4	0	5,700 (5.5)	650 (4.0)	3,280 (21.7)	800 (25.1)	270 (7.0)	2,980 (10.7)	330 (8.2)	1,470 (14.7)	230 (8.3)		.20 (7.5)	8.0 (0.8)
2	4	6,410 (12.8)	840 (9.0)	3,710 (6.1)	810 (5.3)	270 (12.3)	3,170 (12.7)	390 (11.9)	1,510 (18.6)	230 (1.8)		.22 (4.6)	7.0 (2.7)
DUAL PHENOLIC TREATMENT [5]													
12	0	11,510 (6.5)	1,040 (8.0)	7,390 (5.4)	1,080 (5.5)	720 (15.6)	--	--	--	--		.18 (9.6)	5.6 (9.7)
8	4	11,620 (10.5)	1,040 (8.8)	6,950 (7.6)	980 (8.0)	470 (21.4)	--	--	--	--		.22 (.0)	6.3 (5.9)
8	4 [6]	12,310 (9.1)	1,050 (11.3)	7,620 (10.3)	1,040 (9.9)	510 (16.3)	--	--	--	--		.22 (23.3)	5.8 (4.9)
4	8	11,270 (6.4)	920 (8.8)	6,340 (8.6)	1,000 (16.4)	520 (6.5)	--	--	--	--		.28 (5.2)	5.6 (4.9)
4	8 [6]	12,150 (9.0)	1,020 (8.1)	7,230 (9.6)	900 (6.5)	500 (13.9)	--	--	--	--		.25 (5.7)	5.8 (8.0)
0	12	11,620 (11.6)	910 (12.2)	6,050 (24.7)	900 (22.6)	370 (34.2)	--	--	--	--		.26 (12.7)	6.5 (6.5)

[1] Values adjusted to density of 60 pounds per cubic feet and tested according to ASTM D 1037 (see text, footnote 2).
[2] Equilibrium conditioned at each relative humidity (RH) for 30 days.
[3] Values in parentheses are coefficients of variation calculated from five individual values.
[4] Based on dimension at 50 percent RH.
[5] Thermoplastic or medium-viscosity phenolic.
[6] Resins mixed together before spraying.

Table 4.--Physical[1/] and dimensional[2/] properties of 3/16-inch thick medium-density dry-formed aspen hardboards

Resin and amount		Board properties when tested:[3/]									Dimension change with moisture change from 50-90 pct RH[4/]	
Low-viscosity phenolic	Other[5/]	Dry					Wet (after 8-day immersion in water)[4/]					
		Static bending		Tension			Static bending		Tension			
		Modulus of rupture	Modulus of elasticity	Maximum stress	Modulus of elasticity	Internal bond	Modulus of rupture	Modulus of elasticity	Maximum stress	Modulus of elasticity	Length	Thickness
Pct	Pct	Lb/in.²	1,000 lb/in.²	Lb/in.²	1,000 lb/in.²	Lb/in.²	Lb/in.²	1,000 lb/in.²	Lb/in.²	1,000 lb/in.²	Pct	Pct
						PHENOLIC-THERMOPLASTIC COMBINATIONS						
12	0	5,450 (9.3)	570 (7.1)	3,330 (6.8)	550 (6.1)	190 (18.9)	--	--	--	--	0.14 (4.2)	5.5 (4.4)
8	4	4,560 (10.3)	540 (8.8)	2,390 (2.0)	490 (0.8)	120 (11.7)	3,140 (8.0)	380 (7.1)	1,480 (10.8)	300 (5.6)	.14 (7.1)	4.8 (6.0)
4	8	3,470 (24.2)	600 (4.7)	2,190 (5.4)	560 (2.8)	60 (20.6)	2,350 (1.9)	340 (2.8)	1,350 (5.8)	260 (1.6)	.16 (6.9)	5.3 (5.8)
0	12	2,810 (10.5)	540 (7.8)	1,750 (6.9)	540 (3.8)	70 (21.4)	850 (4.6)	150 (1.9)	420 (13.5)	100 (22.2)	.22 (5.1)	7.4 (0.7)
8	0	3,460 (12.5)	440 (10.0)	2,500 (20.3)	470 (12.7)	110 (26.1)	2,460 (11.3)	310 (12.2)	1,380 (13.6)	250 (7.9)	.15 (.0)	6.1 (8.5)
						DUAL PHENOLIC TREATMENT						
12	0	5,450 (9.3)	570 (7.1)	3,330 (6.8)	550 (6.1)	190 (18.9)	--	--	--	--	.14 (4.2)	5.5 (4.4)
8	4	6,320 (4.0)	610 (4.9)	3,210 (10.3)	530 (7.1)	210 (15.5)	--	--	--	--	.16 (3.5)	5.1 (6.5)
8	6/4	6,610 (8.4)	610 (6.4)	4,500 (7.4)	610 (4.9)	210 (18.5)	--	--	--	--	.17 (.0)	5.3 (4.8)
4	8	6,360 (9.1)	540 (14.1)	3,500 (10.9)	490 (9.4)	210 (5.9)	--	--	--	--	.20 (2.8)	5.0 (5.7)
4	6/8	6,390 (16.8)	580 (10.0)	3,790 (7.0)	520 (7.5)	200 (10.6)	--	--	--	--	.20 (3.0)	5.3 (5.9)
0	12	5,640 (21.0)	490 (16.2)	3,550 (9.6)	470 (6.2)	180 (8.3)	--	--	--	--	.23 (10.3)	6.7 (5.1)

1/ Values adjusted to density of 45 pounds per cubic feet and tested according to ASTM D 1037 (see text, footnote 2).
2/ Equilibrium conditioned at each relative humidity (RH) for 30 days.
3/ Values in parentheses are coefficients of variation calculated from five individual values.
4/ Based on dimension at 50 percent RH.
5/ Thermoplastic or medium-viscosity phenolic.
6/ Resins mixed together before spraying.

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MODULUS OF RUPTURE

MODULUS OF ELASTICITY - BENDING

MODULUS OF ELASTICITY - TENSION

TENSILE STRENGTH

175

150

125

100

PROPERTY IMPROVEMENT (pct)

75

50

25

0

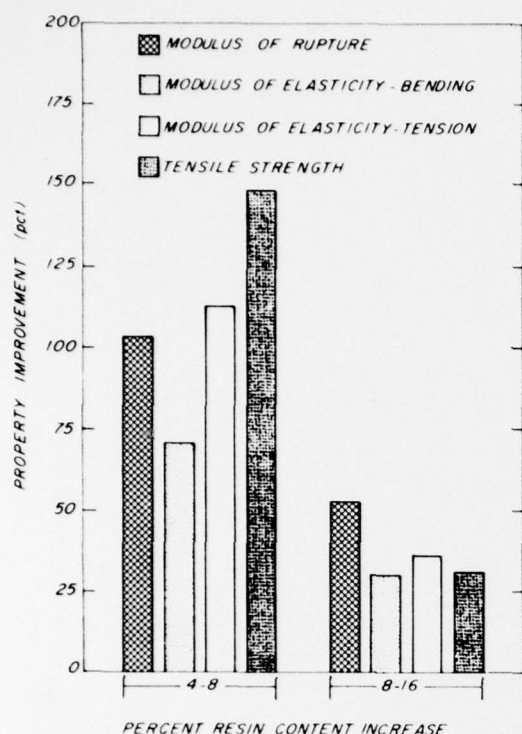|— 4-8 —| |— 8-16 —|

PERCENT RESIN CONTENT INCREASE

Figure 5. -- Relationship of wet property improvements of medium-density boards to doubled amounts of phenolic resin.
(M 144 687)

wet-board property increases were 50 percent and 100 percent, respectively (table 1).

With medium-density boards the wet-board properties were improved most by increasing resin content. For example, figure 5 shows that increasing the resin from 4 percent to 8 percent more than doubled wet-board bending strength, tensile modulus, and tensile strength, and increased the bending modulus by 70 percent. By contrast, increasing the resin from 8 percent to 16 percent improved these wet-board properties by 50 percent or less.

Dual Phenolic Treatment

The low-viscosity (penetrating) and medium-viscosity (typical bonding) phenolic resins were used in combination at the 12-percent level. At this resin level, all properties of the high-density boards were as good or better than those of the boards with only the typical bonding resin, with the exception of bending strength of the 4-percent impregnating plus 8 percent bonding resin applied separately. Either 12 percent or 8 percent

penetrating resin and 4 percent bonding resin mixed before application provided the greatest improvement in all properties--15 percent bending strength and 25 percent for both tensile strength and linear stability (table 3).

The medium-density boards were most improved by combining the 8-percent penetrating resin and the 4-percent bonding resin (table 4). Stiffness was increased about 25 percent as was tensile strength if compared with medium-viscosity resin only. Modulus of rupture was increased 15 percent. Dimensional stability increases were 25 percent for linear stability and 20 percent for thickness swell. Adding all penetrating resin (12 percent) provided the best linear stability, but strength and stiffness properties were reduced. This indicates that, unlike the high-density boards, the medium-density boards need bonding resin to provide optimum properties.

Effect of Phenolic Viscosity

To provide different viscosities for a single resin, carboxymethyl-cellulose (CMC) was added to the low-viscosity phenolic resin to control the penetration of the resin into the fiber.

Adding 1 percent CMC raised viscosity from 11 to 30 centipoises and produced boards with properties similar to the control board, except for tensile strength and modulus that were reduced. By adding 2 percent CMC, viscosity was increased to 90 centipoises; this adversely affected all properties. The reductions apparently were caused, in part, by the inability--with the resin at high viscosity--to treat the fiber uniformly. This was evidenced by some resin spotting on the surface of the boards.

Glass Yarn Scrim

Applying glass yarn scrim to the surface of the hardboard effectively improved strength, stiffness, and linear stability of the hardboards (table 5). One layer of scrim applied to both board sides constituted only 1 percent of the weight of the medium-density boards, increased the bending strength 35 percent, the bending modulus 25 percent, and lowered the linear movement 40 percent for a moisture change of from 50 to 90 percent relative humidity. Bending failure in dry-formed hardboards generally occurs on the compression side. With the glass scrim the failure shifted from a compressive to a tensile failure. This had only a minor effect on compressive strength and on modulus of elasticity in tension and compression. The use of two layers of glass on each side rather than a single layer

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Table 5.--Physical[1] and dimensional[2] properties of dry-formed ponderosa pine hardboards reinforced with glass fiber scrim[3]

Board composition		Static bending		Tension			Compression (parallel to surface)		Dimension change[6] with moisture change from 50-90 pct RH	
Glass scrim[4]	Resin content (wood fiber)[5]	Modulus of rupture	Modulus of elasticity	Maximum stress	Modulus of elasticity	Internal bond	Maximum stress	Modulus of elasticity	Length	Thickness
Plies/side	Pct	lb/in.²	1,000 lb/in.²	lb/in.²	1,000 lb/in.²	lb/in.²	lb/in.²	1,000 lb/in.²	Pct	Pct
				MEDIUM-DENSITY BOARD 7/16-INCH THICK						
0	8	4,000 (11.0)	520 (7.0)	2,290 (6.2)	570 (11.4)	20 (.0)	2,240 (7.3)	490 (3.8)	0.25 (2.9)	7.8 (.0)
1	8	5,480 (7.3)	670 (4.0)	3,010 (8.1)	550 (6.7)	40 (13.7)	2,360 (15.9)	530 (12.4)	.15 (4.9)	7.7 (2.8)
2	8	5,980 (9.8)	810 (4.8)	3,330 (9.0)	620 (18.7)	45 (13.5)	2,550 (10.4)	570 (8.5)	.12 (.0)	7.7 (1.8)
0	12	6,080 (24.5)	650 (4.0)	3,510 (4.4)	660 (9.5)	40 (40.9)	3,470 (19.1)	590 (12.9)	.24 (3.0)	6.1 (4.6)
1	12	7,500 (9.2)	760 (2.4)	4,210 (4.3)	610 (2.6)	80 (19.0)	3,200 (11.4)	590 (6.9)	.17 (.0)	6.0 (1.2)
2	12	8,140 (9.8)	890 (2.6)	4,530 (5.7)	650 (4.6)	75 (14.0)	3,420 (10.6)	650 (10.9)	.14 (5.2)	6.0 (5.9)
2	15	9,600 (4.9)	910 (4.9)	4,510 (13.1)	668 (10.5)	85 (18.4)	--	--	.13 (5.7)	5.6 (3.8)
				HIGH-DENSITY BOARD 1/8-INCH THICK						
0	2	5,700 (27.4)	670 (19.1)	2,830 (23.8)	620 (25.1)	195 (51.7)	--	--	.27 (5.2)	10.8 (12.5)
1	2	8,870 (14.3)	1,130 (7.2)	6,500 (12.0)	880 (9.0)	--	--	--	.03 (84.9)	9.9 (1.4)
0	4	7,820 (27.4)	740 (19.0)	5,300 (24.3)	790 (16.8)	510 (13.9)	--	--	.22 (6.4)	8.8 (22.5)
1	4	11,410 (14.7)	1,190 (7.6)	6,780 (7.8)	850 (6.4)	--	--	--	.02 (115.7)	7.1 (6.0)
0	8	8,930 (7.9)	790 (6.4)	6,040 (18.3)	900 (13.2)	475 (21.1)	--	--	.27 (2.7)	7.3 (.0)
1	8	12,460 (4.0)	1,180 (4.8)	7,920 (11.8)	1,050 (5.9)	--	--	--	.08 (9.4)	6.2 (13.7)
2	8	15,380 (10.1)	1,640 (2.6)	9,460 (3.2)	1,190 (4.1)	--	--	--	.03 (28.3)	5.6 (.0)

1/ Mechanical properties except internal bond adjusted to densities of 60 pounds per cubic feet for high-density and 50 pounds per cubic feet for medium-density boards and tested according to ASTM D 1037 (see text, footnote 2).
2/ Equilibrium conditioned at each relative humidity (RH) for 30 days.
3/ Values in parentheses are coefficients of variation calculated from five individual values.
4/ Treated with approximately 16 percent of an alcohol-soluble phenolic resin (based on weight of glass).
5/ Treated with a low-viscosity phenolic resin (percent based on dry fiber weight).
6/ Based on dimension at 50 percent RH.

did not greatly improve the properties. The results indicated that perhaps it would be more advantageous to increase the amount of resin on the wood fiber.

The glass scrim had a greater effect on stiffness and linear movement of the high-density boards than on that of medium-density boards. The tensile modulus increased substantially but more surprising was the large reduction in linear change with increases in moisture. This was a permanent effect; repeated cycling between a low and high humidity did not alter the degree of stability observed in the initial absorption cycle.

In commercial operation, the pretreated glass could be applied by feeding the glass scrim continuously onto the moving wire before laying down the fibrous mat and onto the top of the mat after "scalping" the excess buildup of wood fiber. No economic analysis was made of the additional cost required for this procedure.

Conclusions

Based on the findings of this work, hardboard stiffness and dimensional stability can be improved by increasing phenolic resin content, combining penetrating- and bonding-type phenolics, or by bonding glass yarn scrim to the board surface.

Powdered thermoplastic resin can be substituted for phenolic resins under dry conditions and can also be used as a partial replacement for a phenolic resin and still provide good wet-board strength, stiffness, and dimensional stability more economically.

On an equivalent cost basis, phenolic-thermoplastic combinations can be effective in providing boards with improved overall properties.

U.S. Forest Products Laboratory.
    Resin systems and glass reinforcements to improve dry-formed hardboards, by P. E. Steinmetz. Madison, Wis., For. Prod. Lab. 1977.
    11 p. (USDA For. Serv. Res. Pap. FPL 284).

    Resin systems and quantities of resin and a glass yarn are investigated to determine their effect on board stiffness and linear stability.

KEYWORDS: Hardboards, thermoplastic resin, two-part epoxy resin, low- and medium-viscosity phenolic, glass yarn scrim, stiffness, linear stability.